



High Temperature Joining and Characterization of Joint Properties in Silicon Carbide-Based Composite Materials

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Outline

- **Introduction and Objectives**
 - Critical Needs and Benefits
- **Ceramic Joining Technologies: Overview**
- **High Temperature Reactive Pastes - *Single-step Elevated Temperature (SET) Joining***
 - *Characterization of the paste*
(Particle size effect, conversion, and microstructure)
- **Future Plans - *Mechanical testing of sub-elements and subcomponents***
- **Summary/Conclusions**

Goals and Objectives

Goals:

Deliver the benefits of ceramics in turbine engine applications: higher temperature capability, and reduced cooling and weight, which contribute to increased efficiency, performance, horsepower, range, and payload, and lower operation costs for future engines.

Objectives:

Develop joining and integration technologies which enable the wider utilization of ceramic matrix composite (CMC) turbine engine components by allowing for the fabrication of complex shaped CMC components and their incorporation within surrounding metal based systems.



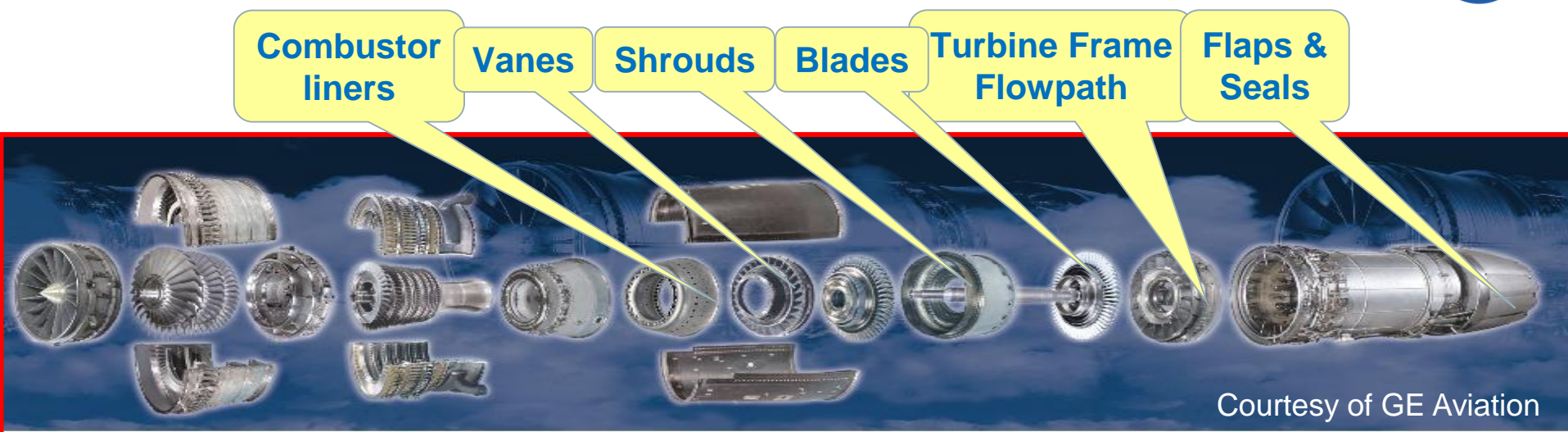


Joining and Integration of Ceramics and CMCs for Turbine Engine Components

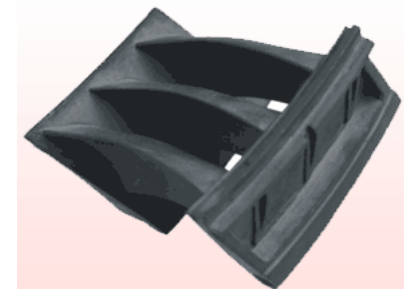
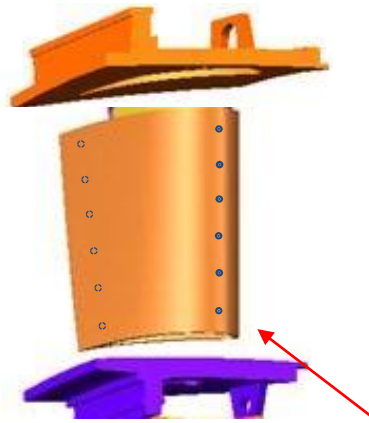
Approach

- Develop single, multiple, and hybrid interlayer approaches to aid in the joining of CMCs to CMCs and to metals.
- Optimize processing conditions so that joints and parts remain strong and crack free.
- Investigate inter-relations between processing, microstructure, and properties.
- Evaluate the thermal and mechanical properties of the joint.
- Scale-up of processing to larger and more complex shaped sub-components.
- Evaluate joints in relevant conditions which are comparable to engine operating environments.

CMC Turbine Engine Components and Joining Needs



Joining of singlet vanes to form doublets and joining of vane airfoils to ring sections (for smaller engines) - Allows for a reduction in part count, seals, and leakage

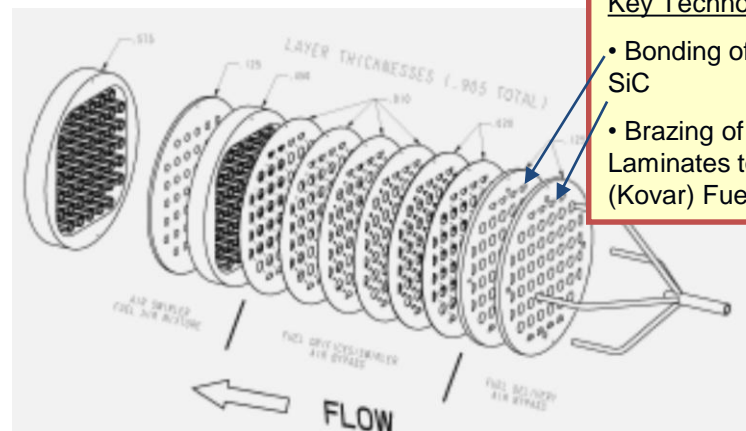


Joining of airfoil and end caps
- Easier fabrication compared to a continuous 3-D CMC vane

Potential Applications for Ceramic to Metal Integration

Lean Direct Fuel Injector

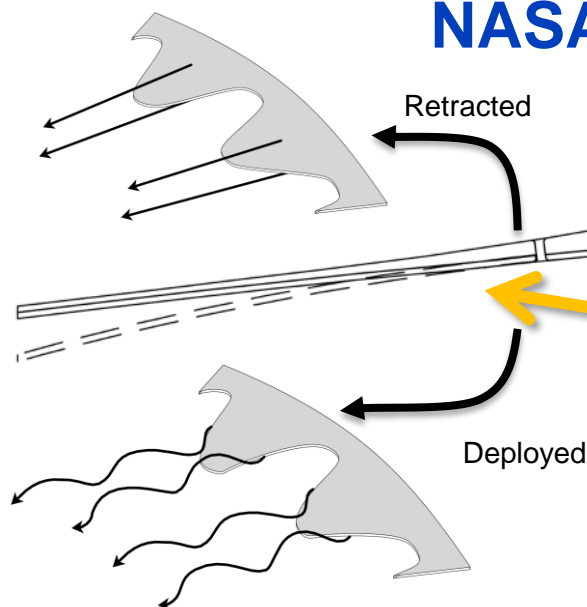
Enabling for internal fuel circuit, sensor and actuator integration, and incorporation into metallic fuel system



Key Technologies:

- Bonding of SiC to SiC
- Brazing of SiC Laminates to Metallic (Kovar) Fuel Tubes

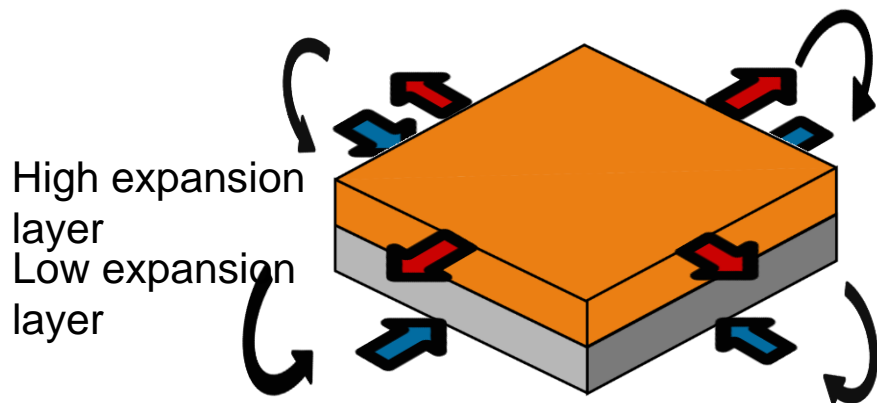
NASA/Boeing Variable Geometry Chevron



“Chevrans” could deploy on takeoff to reduce jet noise, retract in cruise to reduce drag.
Concept courtesy of Eric Eckstein, University of Bristol, U.K.

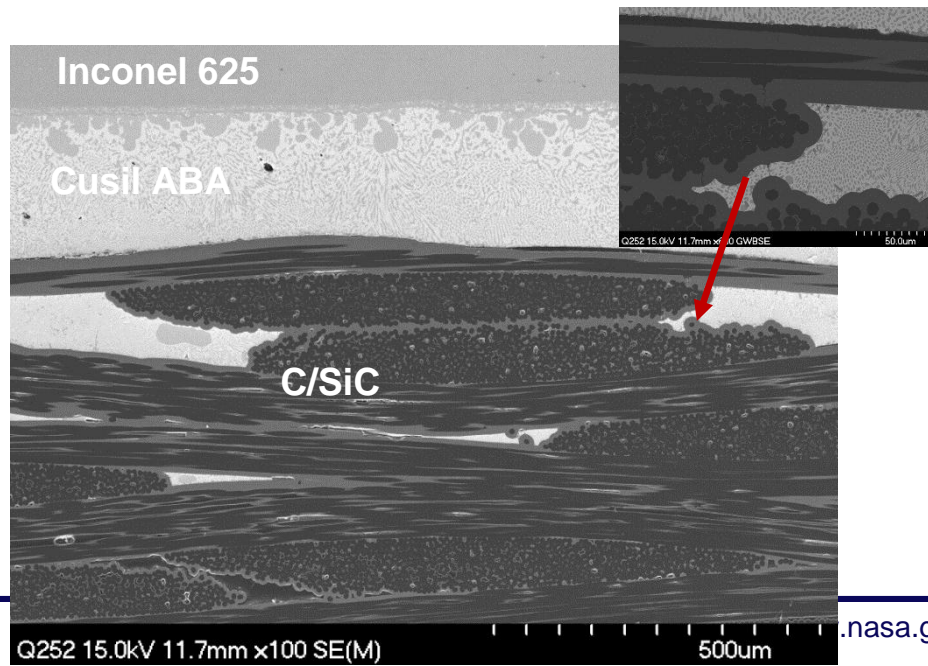
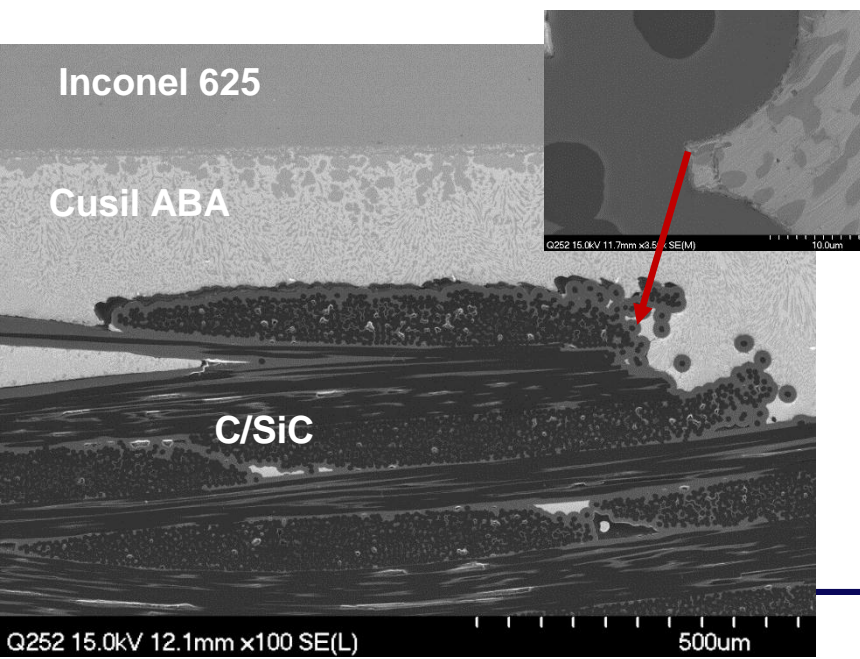
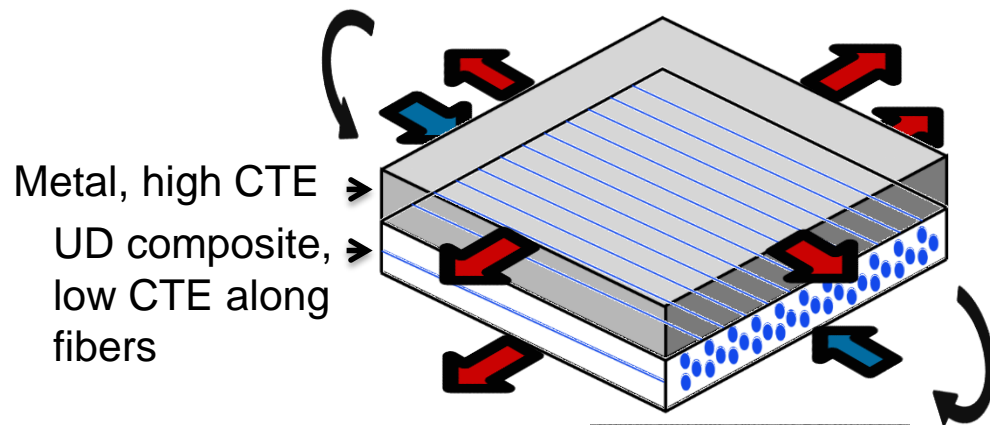
Thermally-Actuated, High Temp. Morphing Composites

Isotropic Bimorph- Omnidirectional Moments



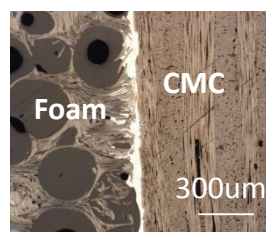
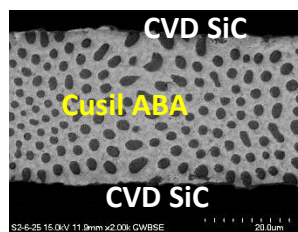
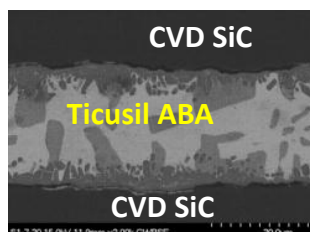
Courtesy of Eric Eckstein, University of Bristol, U.K.

Composite Construction Allows General Planforms



Integration and Joining Technology Development

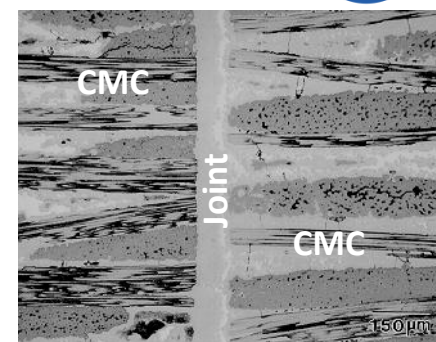
Ceramic to Ceramic (CMC to CMC) System:



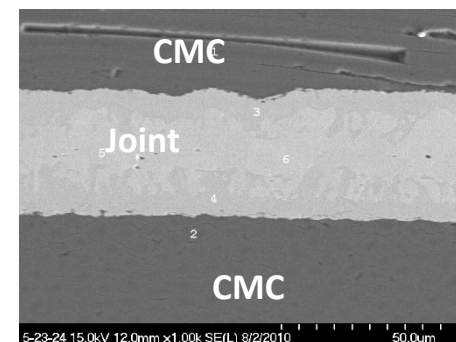
Brazing Examples

- **Brazing** - liquid metal flows into a narrow gap between the mating surfaces and solidifies to form a permanent bond. *Also for ceramic to metal joining.*
- **High Temperature Reactive Joining** - two step reactive formation of high temperature capable joints using carbon paste and Si infiltration (**ARCJoinT**).
- **Diffusion Bonding** - mating surfaces are pressed together and heated to cause bonding by interdiffusion of the components.
- **Refractory Eutectic Phase Bonding** - melting of a eutectic phase from a solid to a single phase liquid (**REABond**).

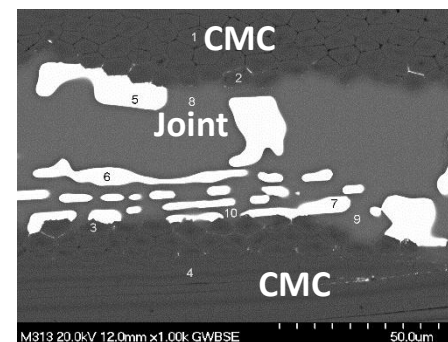
Uniform, dense, crack-free joints from all approaches.



ARCJoinT



Diffusion Bonding



Eutectic Phase Bonding



High Temperature Joining Approaches

Limitations of Current Joining Approaches

Non-SiC-Based Approach

- Chemical and thermal incompatibility of interlayer and substrate
- Residual thermal stresses => lower strength, microcracking, and debonding
- Low temperature capability than parent material capability
- Formation of intermediate or non-favorable phases

Other SiC-Based Approaches

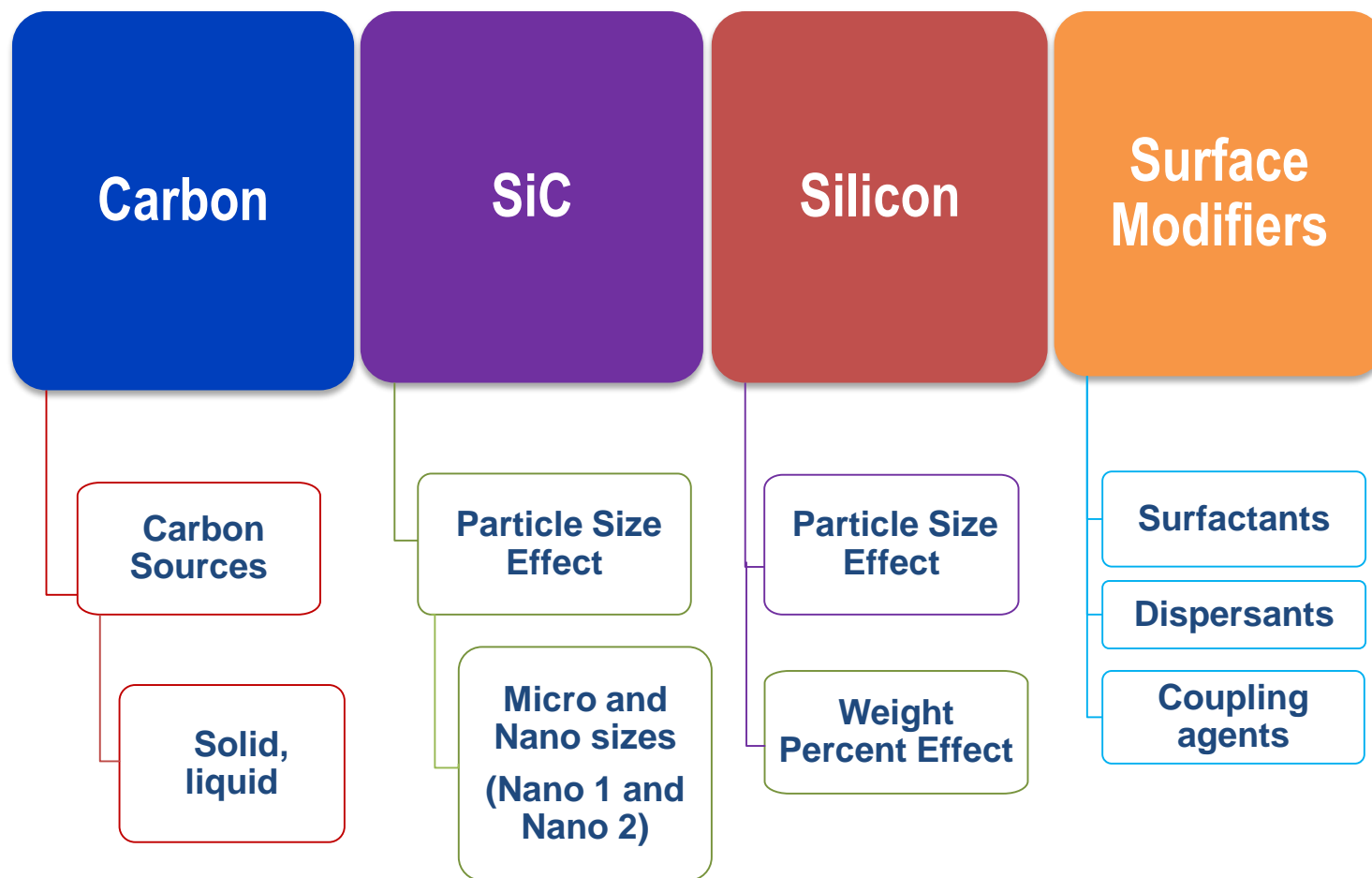
- Two-step, two-phase processes
- Residual carbon is prone to oxidation leading to porosity
- Residual silicon lowers temp. capability to <2400°F (1316°C)

A new high temperature SiC-based joining approach is needed.

Overview of Pre-ceramic Paste Composition for High Temperature Joints

- Single-step Elevated Temperature Joining (SET)

J5A, J5A Nano 1, J5A Nano 2 - in descending order of SiC particle size



Furnace Weight Loss Studies

Materials:

J5A, J5A Nano 1, and J5A Nano 2 + 10, 20, 30 wt% Silicon

Procedure:

Cure

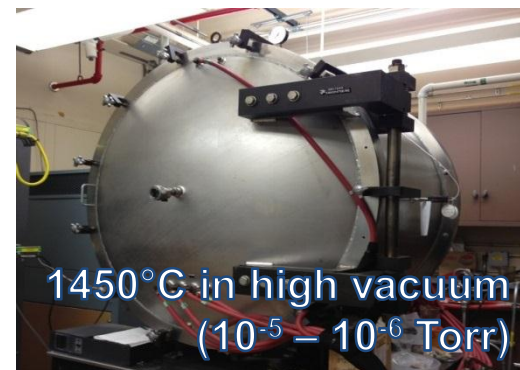
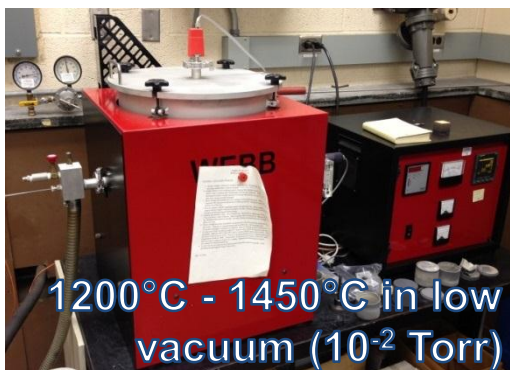
90°C overnight

**Binder
burnout**

1000°C in Argon

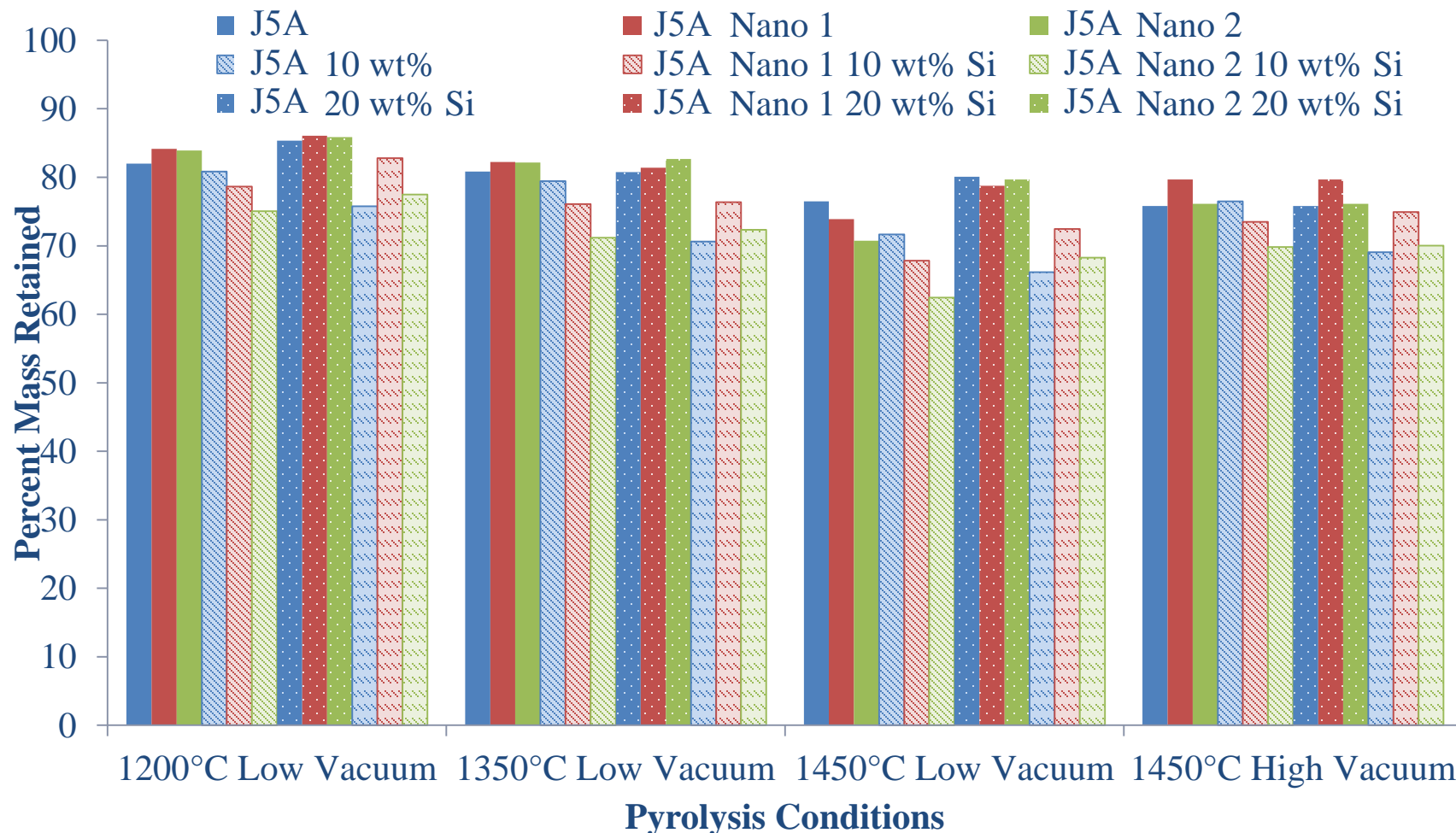
Pyrolysis

1200°C, 1350°C, or
1450°C





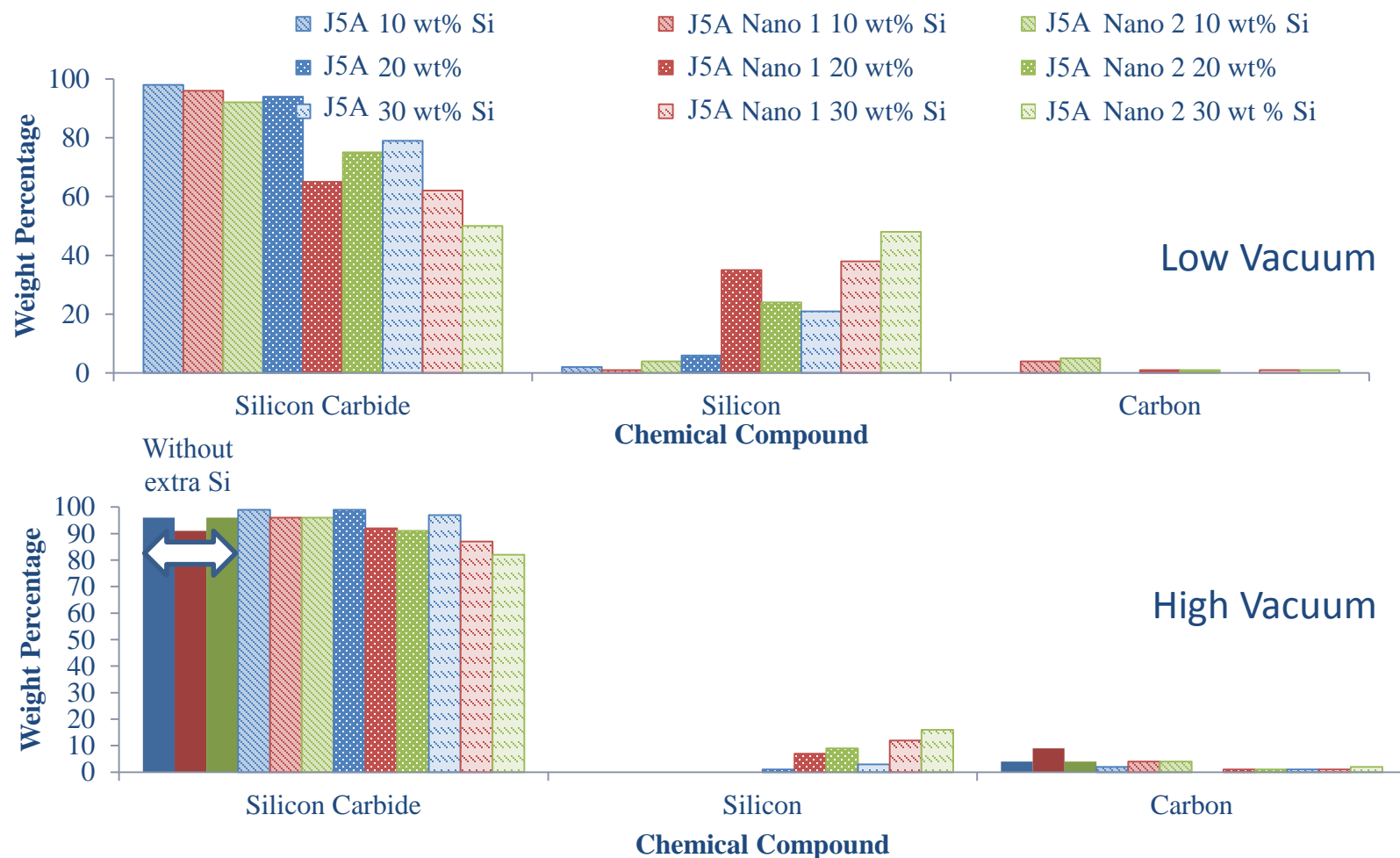
Weight Retention of Pre-Ceramic Pastes



Weight retention values are promising for all samples → secondary infiltration steps may not be necessary

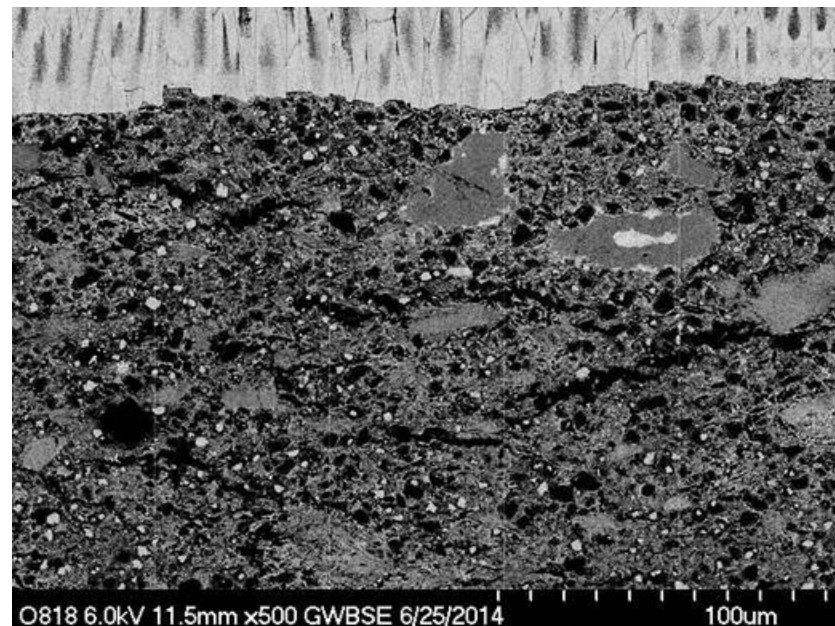
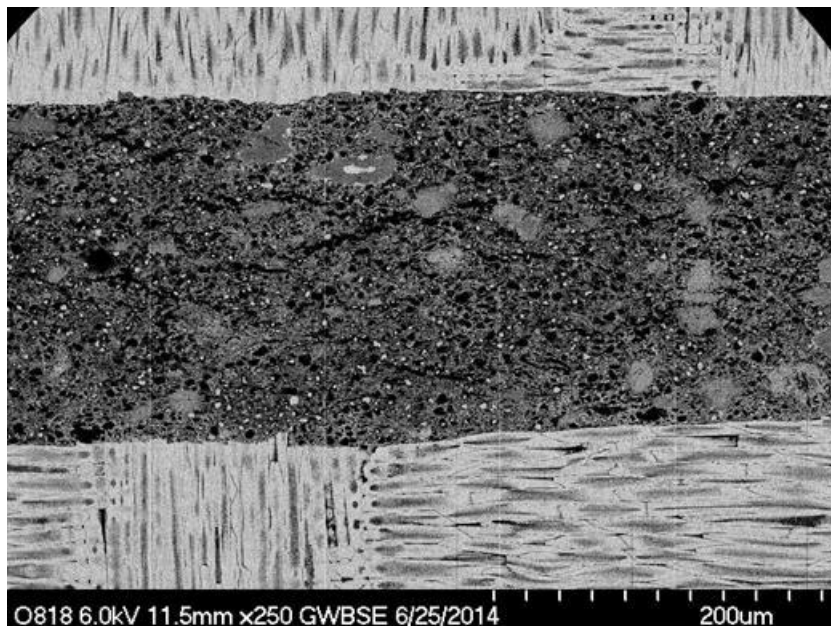
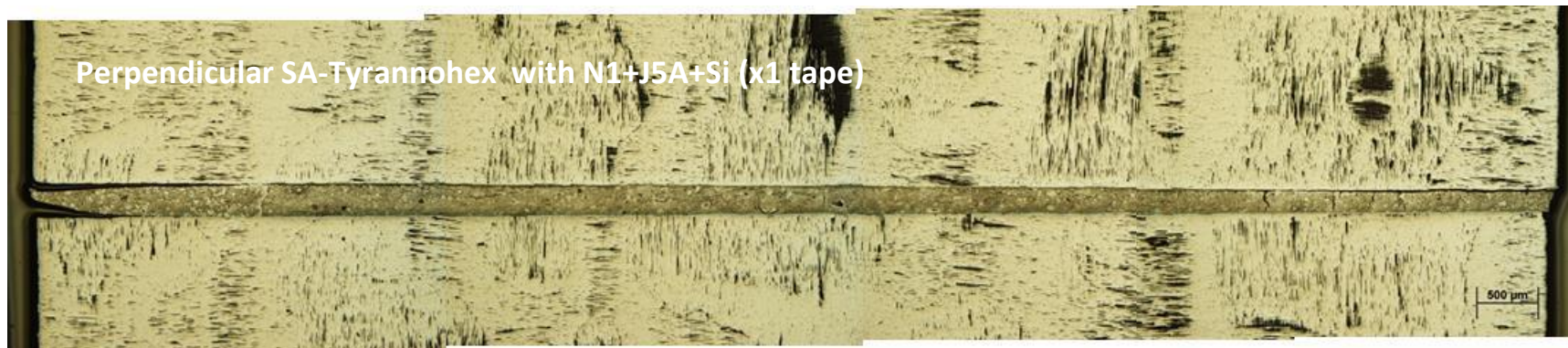
Weight loss trends found in furnace weight loss studies similar to TGA data

Chemical Composition of Heat-treated Pastes at 1450°C (from X-Ray Diffraction Analysis)



- All compositions after pyrolysis show a high yield of SiC.
- Vaporization of Si occurs in vacuum due to its high vapor pressure.

Joining of SiC-Based Composites Using Pastes - Perpendicular SA-Tyrannohex with N1+J5A+Si



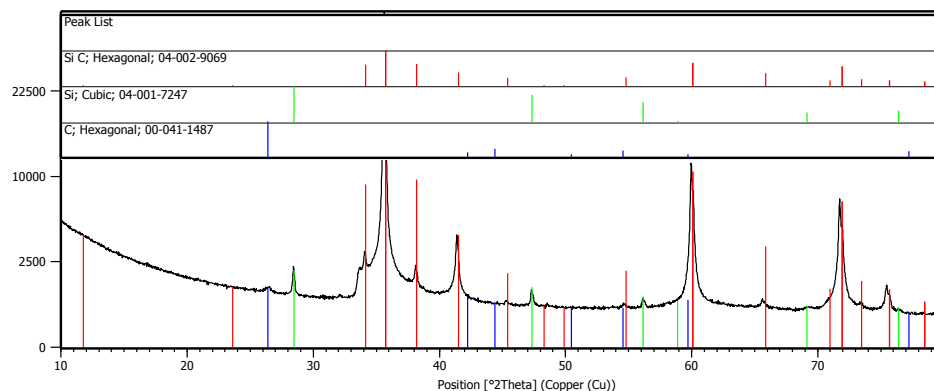
Single-Step Elevated Temperature Joining: Higher Temperature Capable C, Si, and SiC-Based Pastes

Approach: 30 mil thick green tapes of SiC, Si, and carbon powders of varying particle sizes as well as several other additives.

Benefits: high temp. capability and one-step SiC formation.

X-Ray Diffraction analysis of three slurry compositions heat treated at 1450°C for 30 min.

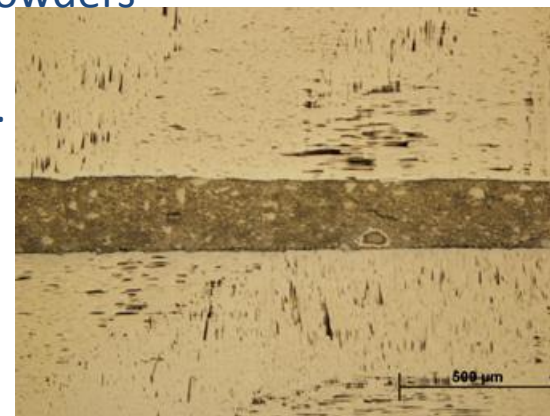
Counts



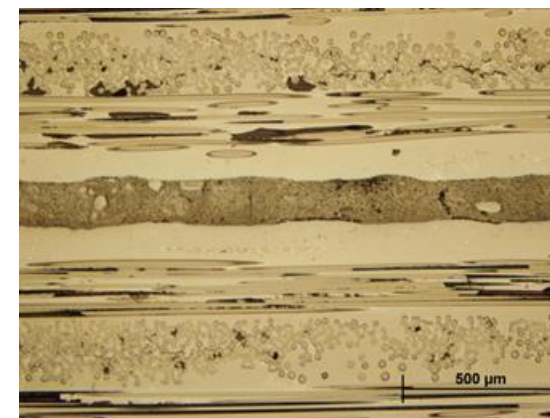
SemiQuant (%)

Composition	SiC	Si	C
J5A+Si	99	1	0 -nearly complete SiC conversion
J5A+N1+Si	91	9	1
J5A+N2+Si	92	7	1

High conversion to SiC suggests the compositions will provide one-step SiC formation.



J5A+N2+Si Joining of SA-THX (L orientation)

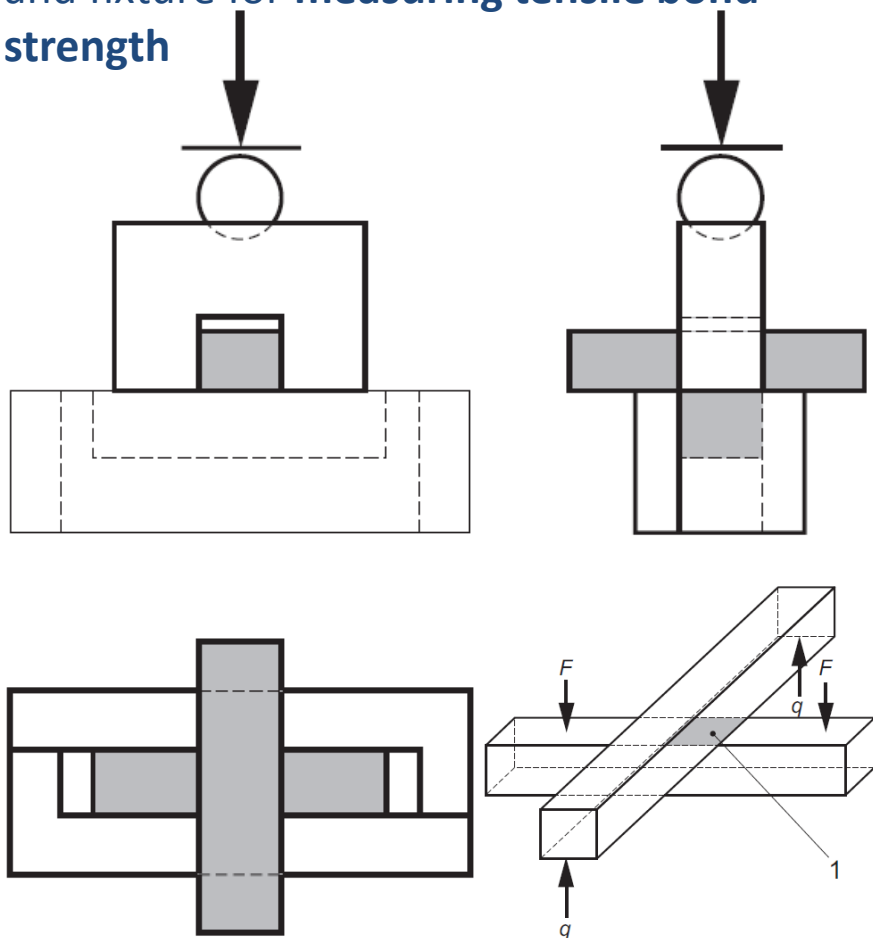


J5A+N1+Si Joining of SiC/SiC

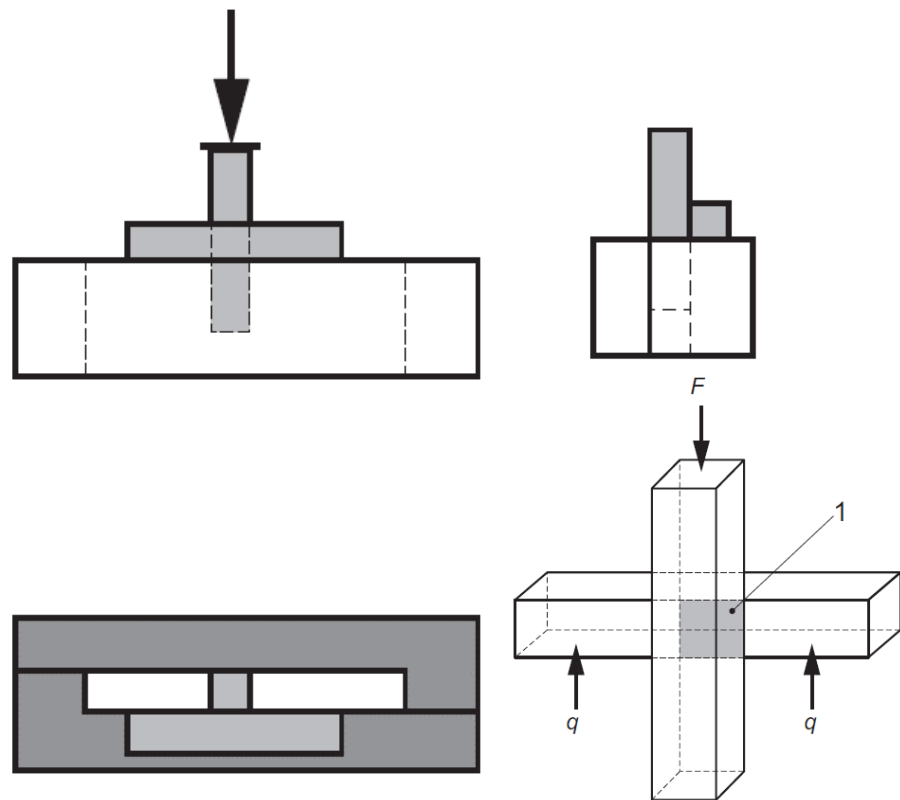
Good initial results with J5A+N1+Si and J5A+N2+Si. Repeat and optimize with J5A+Si for less shrinkage.

Mechanical Testing: In-House Capability for Testing According to ISO 13124

Schematic diagram of cross bonded sample and fixture for **measuring tensile bond strength**



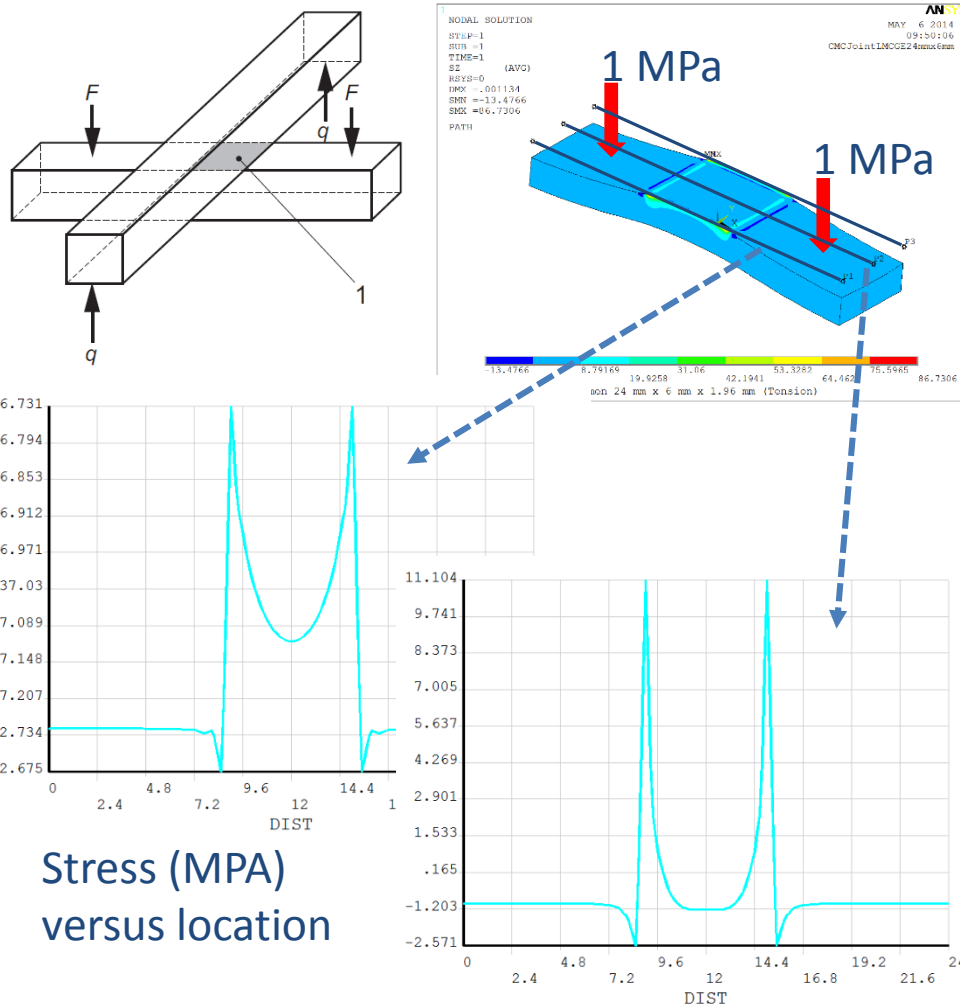
Schematic diagram of cross bonded sample and fixture for **measuring shear bond strength**



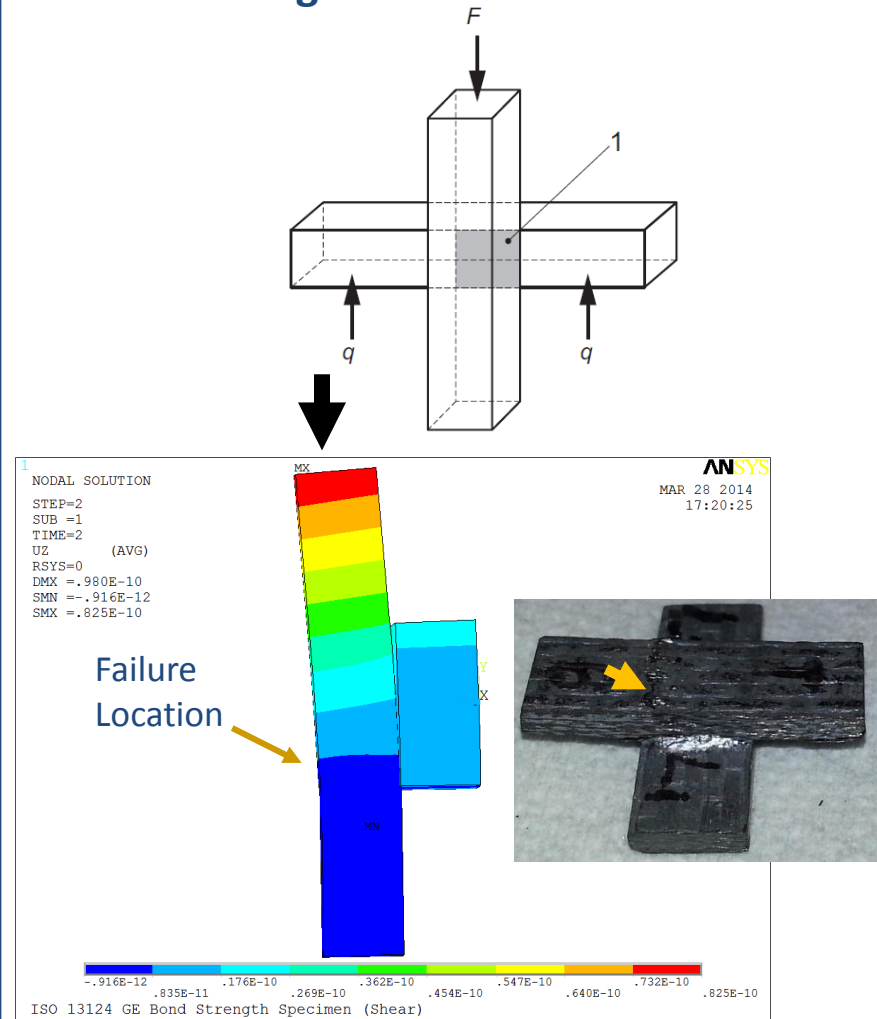
INTERNATIONAL STANDARD ISO 13124 First edition 2011-05-15: Fine ceramics (advanced ceramics, advanced technical ceramics) - Test method for interfacial bond strength of ceramic materials

Results and Analysis for Testing to ISO 13124 (with REABond Joining)

Testing in Tension

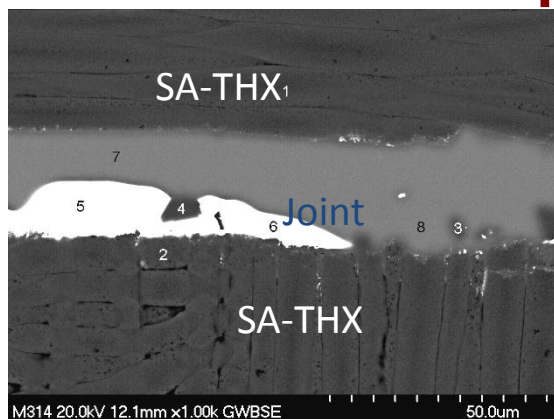


Testing in Shear

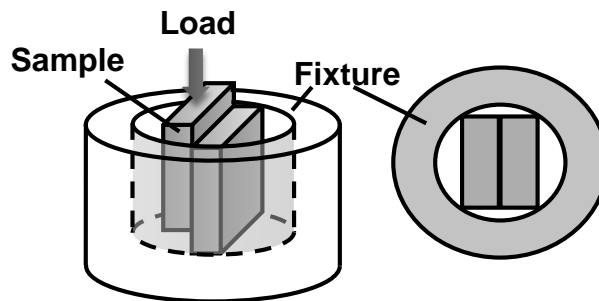


Results show the need for additional analysis and improved test methods.

Mechanical Testing: Single Lap Offset - REABond Joined SA-Tyrannohex

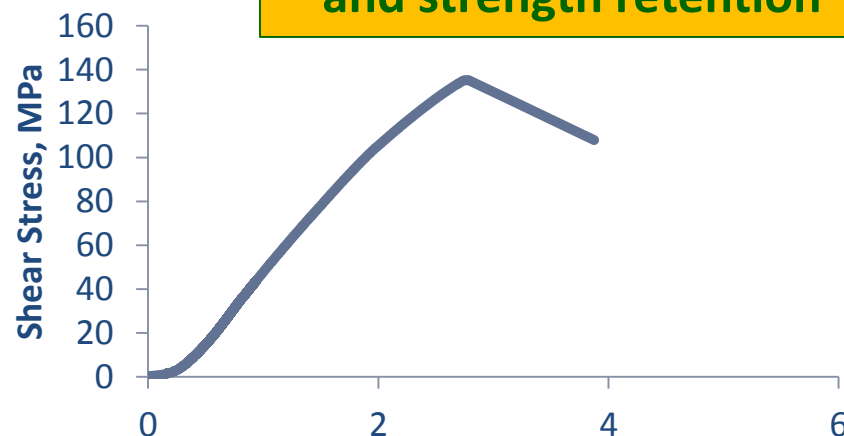
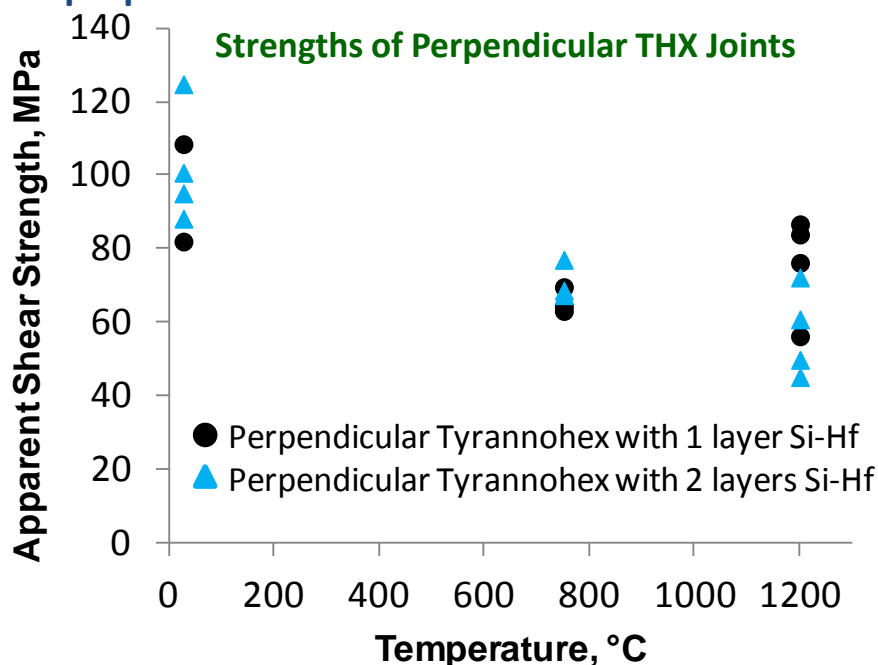


As-processed joint for SA-THX
in perpendicular orientation



Test configuration for single
lap offset shear test

**Excellent joint stability
and strength retention**



Residual Strength Test % Strain

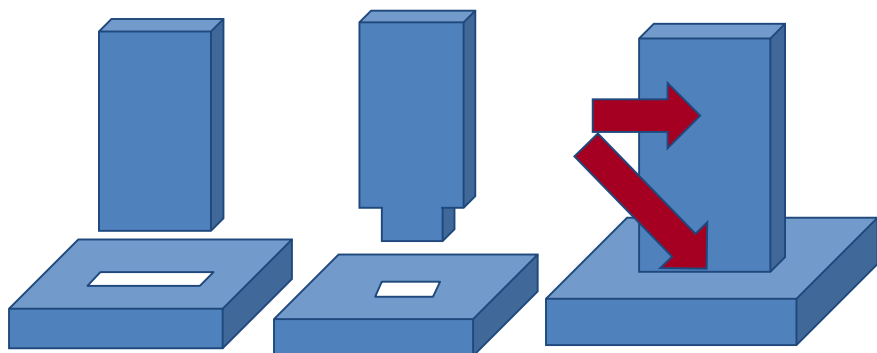
- 350 hr run out at 1200°C and 25 MPa
- tested at 1200°C
- highest strength seen in a SLO test, 135 MPa

Single lap offset shear test to be used for in-house screening.

Joining Technology Demonstration

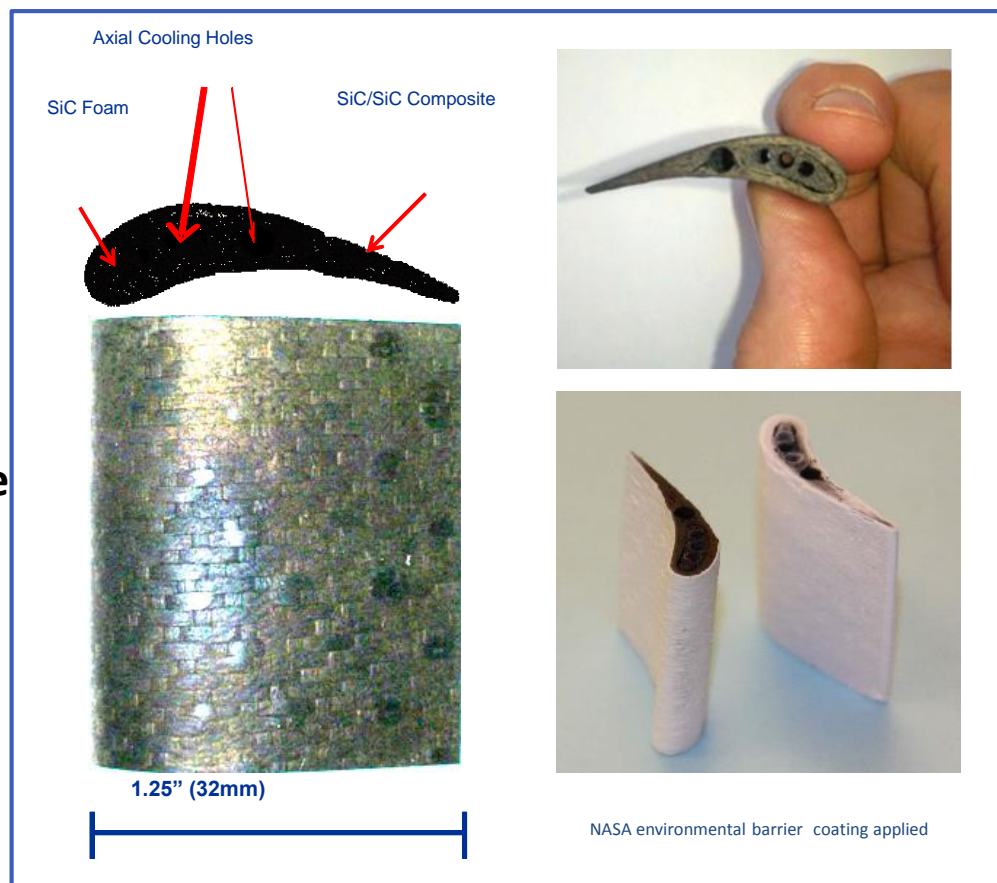
- Sub-element tests in a relevant environment

Goal: Apply joining to sub-elements and sub-components and test to higher TRL in under relevant conditions.



Steps:

- Join coupons to form profiles of vane/blade sub-elements.
- Conduct thermal exposures and evaluate residual strength and damage (microscopy and NDE). Also conduct strength tests on non-exposed sub-element(s).
- Introduce mechanical stress for thermo-mechanical conditions, i.e. 2400°F laser induced thermal gradient exposure. Laser focused at airfoil or joint region.





Conclusions

- Current joining methods have limitations:
 - Use temperatures are limited to $<2400^{\circ}\text{F}$ (1316°C) and much lower
 - Chemical and thermal incompatibility with SiC/SiC CMCs
- The Single-step Elevated Temperature (SET) joining approach offers:
 - No residual C or Si
 - High weight retention and SiC conversion
 - Use temperatures $>2400^{\circ}\text{F}$
 - Good joint formation observed, some optimization needed
- New test methods are needed to evaluate joining approaches
- The SET joining will be demonstrated to a higher TRL through single-lap offset shear tests and demonstration of joined vane sub-elements in relevant thermo-mechanical engine conditions



Acknowledgements

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